

Chapter

Functionality and Value of Green Infrastructure in Metropolitan Sprawl: What Is the City's Future? A Case Study of the Bogotá-Sabana Northern Region

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Abstract

From the planning perspective, green infrastructure emerges as an effective strategy to address the effects of climate change and its negative impacts on urban growth. Consequently, the concept of green infrastructure represents a paradigm shift in the way in which green open space is conceived from the urban growth perspective. The concept of green infrastructure has featured prominently in urban planning since the late twentieth century. Thus, this study aims, firstly, to determine the functionality of green infrastructure in terms of population density; and secondly, to evaluate the effects of urban expansion plans on sustainable development of green infrastructure. The research applied as methods multispectral satellite imagery information to obtaining a Normalised Difference Vegetation Index (NDVI) and space syntax related with urban morphology. As main conclusion, in the municipality, there is a disconnection and disarticulation between public spaces and green areas, with the main uses, activities and facilities, as well as a road infrastructure having no connectivity. Furthermore, there is no evidence of biomass corridors that connect the space between the rivers, and the green areas identified through the NDVI analysis result more commonly to be none build areas, or low density edifications and rarely parks or natural corridors where biomass is meant to be preserved.

Keywords: green infrastructure, metropolitan urban sprawl, space syntax, climate change, urban development

1. Introduction

1.1 Green infrastructure: Concepts and planning

The concept of green infrastructure, as opposed to grey infrastructure, refers to open-space systems in cities. From the planning perspective, green infrastructure

emerges as an effective strategy to address the effects of climate change and its negative impacts on urban growth [1]. Therefore, it is imperative to specify the scope of the green infrastructure concept, its objectives, principles and functions, in addition to the challenges stemming from the planning and land management fields in a metropolitan context. These challenges refer, on the one hand, to the necessary integration of green spaces planning in a physically and functionally interconnected system in the territory, and on the other hand, to an effective use of the ecosystem services that these spaces provide to the territory [2].

Consequently, the concept of green infrastructure represents a paradigm shift in the way in which green open space is conceived from the urban growth perspective. According to Benedict et al. [3], green infrastructure contributes to mitigate the ecological and social problems associated with new models of diffused urban growth, accelerated land consumption and progressive fragmentation of natural areas contribute to this. Benedict et al. also define green infrastructure as an interconnected network of green spaces that conserves the functions and values of natural ecosystems, hence extending benefits to the population [3]. Thus, the importance of the role of natural ecosystems in urban planning and development is evidenced highlighting the systemic vision in the urban growth process [4]. In brief, the contemporary shift in the green infrastructure concept emphasises the functions and benefits of green spaces provided to cities, particularly to those belonging to an interconnected and multi-scale system [5].

The concept of green infrastructure has featured prominently in urban planning since the late twentieth century [6]. According to Rouse et al. [7], as cited by Giannotti et al. [5], in the United States, the green infrastructure concept has been used since the 1990s, especially to refer to sustainable rainwater management. According to the same authors, in Europe, the term has started to be used more recently, focusing on ecological connectivity for the preservation of biodiversity and the provision of ecosystem services in both urban and rural territories. According to European Union (EU) public policy documents, green infrastructure should constitute a network of natural and semi-natural areas and other environmental elements, which are strategically planned, designed and managed for the provision of a wide range of ecosystem services [8].

1.2 Objectives and functions of green infrastructure

Mas et al. [1] refer to research advanced by the EU Working Group on Green Infrastructure according to which green infrastructure key goals are, firstly, the promotion of integrated territorial planning through identification of multifunctional areas and incorporation of habitat restoration policies related to land use; secondly, a better adaptation of society and territory to climate change scenarios; thirdly, the improvement of ecosystem services; and finally, a contribution to biodiversity conservation. Therefore, green infrastructure in urban systems has a multifunctional character with environmental, social and economic functions and value as productive areas and potentially increasing land values of surrounding areas [1].

Ramos et al. [2] provide a detailed characterisation of the functions related to green infrastructure in terms of their value as a network and other features associated with the territorial matrix. On the one hand, these authors stress functions linked to a green infrastructure network and the conservation of natural habitats that may be affected by land use dynamics, urban growth and the expansion of artificial infrastructures evidencing the importance of green infrastructure to re-establish

the connectivity lost in natural habitats as a consequence of urban growth processes. Secondly, Ramos et al. point to the establishment of a system of public spaces for public recreational use and sustainable mobility for inhabitants. On the other hand, the authors propose functions associated with the territorial matrix, that is, firstly, environmental regulation functions against the impacts of phenomena associated with climate change and the so-called urban heat island; and secondly, provision functions related to the potential use of the green infrastructure system for urban agriculture. In short, green infrastructures provide diverse ecosystem services for urban populations, understood as benefits that society derives from such ecosystems [6, 9]. In a metropolitan context, these services range from the conservation of natural assets to the reduction of air pollution and the mitigation of climate change effects, as Manes et al. [10] analyse for the case of Metropolitan Rome. A highly relevant aspect of this association between green infrastructure and ecosystem services refers to the capacities of the former to spatialise the latter and to thus being able to establish the regional and local deficits of green infrastructures on the urban planning perspectives [4].

1.3 Green infrastructure in land-use planning and management

From a spatial planning perspective, the connectivity and multifunctionality of green infrastructure are two key aspects of public policies [11]. On the one hand, the connectivity concept highlights the value of green infrastructure networks for urban growth. On the other hand, the multifunctionality concept highlights the central role green infrastructure plays in territorial planning processes as strategic infrastructures for the sustainability of urbanised areas [2]. Therefore, from a land-use planning perspective, green infrastructure planning must compensate urban development while seeking to enhance connectivity with metropolitan natural border systems. Furthermore, as Mell [12] states, green infrastructure planning should rethink relations with natural systems on a metropolitan scale. In addition, green infrastructure planning policies must consider a multi-scalarity perspective to encourage an adequate articulation with urban centres [6]. This conceptual approach is a paradigm shift in spatial planning. According to Buzai et al. [4], urban models have historically emphasised economic, land rent and ecological aspects in terms of socio-spatial distribution of the population, but they have not made clear reference to land uses of natural components. Consequently, green infrastructure system planning appears even more valuable. Therefore, from a more holistic urban planning perspective, green infrastructure planning should include metropolitan green belts containing dispersed urban growth and linear parks alongside rivers that protect water resources, among other strategies [4]. A broad participation of diverse stakeholders, including public policymakers, firms, conservation entities and landowners is necessary to ensure the benefits of green infrastructures planning.

Giannotti et al. [5] study the 'Stgo+ Green Infrastructure' project in Santiago de Chile to understand how the issue of the climate emergency has been taken in consideration in green infrastructure planning and its level of priority among various types of stakeholders. Giannotti et al. conclude that stakeholders' highest priorities are the inequality in the accessibility of green areas and the potential benefits of green areas. Therefore, a key factor in green infrastructure planning and adaptation to the climate emergency should emphasise environmental justice and equity. Mas et al. [1] study the urban environmental corridor of the Manzanares River in Madrid concluding that green and blue infrastructure is relatively well implemented in climate adaptation and mitigation strategies at the European level. However, the authors highlight

some lines of work that can be reinforced such as the promotion of integrated spatial planning approaches and methods to stimulate cross-sectoral regional cooperation, as well as the application of environmental-based measures in decision-making on issues related to climate adaptation and mitigation. Ramos et al. [2] analyse the provision of ecosystem services in Seville, Spain, which are based on the mapping of environmental multifunctionality in the Seville metropolitan area. The authors calculate a set of indicators jointly with the estimation of a synthetic index of green infrastructure multifunctionality. Ramos et al. conclude that both the articulation in a network of parks and natural areas and the enhancement of multifunctionality of the landscape are two essential pillars of the management of metropolitan green infrastructure. Moreover, the authors highlight the territorial matrix role and especially of agricultural areas as essential components of a multifunctional green infrastructure. For this purpose, Ramos et al. state that the Geographical Information System (GIS) is a powerful tool to facilitate the integration and spatialisation of green infrastructure designs [6].

From this perspective, the Chía, Colombia, in the case study of the Bogotá-Sabana Northern region, and more specifically in the case of the metropolitan city of Chía, which is analysed in this chapter, follows the line of argument on the role of green infrastructure in metropolitan growth, especially in metropolitan sprawl. The municipality of Chía is located in the northern Bogotá metropolitan region. Low-density and discontinuous suburban growth going beyond residences and also including educational infrastructure and offices is a pattern of the urban growth of the city [13, 14]. A major impact on the city's rural areas is unfolding, especially along the Bogotá and Frío rivers, which is leading to a fragmentation of green infrastructure and a reduction in its value and functionality for the inhabitants. **Figure 1** shows the overview landscape of the Chía case study.

Thus, this analysis aims, firstly, to determine the functionality of green infrastructure in terms of population density; and secondly, to evaluate the effects of urban expansion plans on sustainable development of green infrastructure. This study develops two research questions:



Figure 1.
Overview of landscape of Chía. Source: Authors.

How do urban green infrastructure systems contribute to urban vitality and sustainable growth in minor cities of metropolitan areas?

Does metropolitan sprawl encourage better proximity and functionality of urban green infrastructure?

Through this study, the implications and results could be used by policymakers, public officials and other stakeholders in urban planning to make informed decisions regarding strategies for the protection of green infrastructures and their adequate articulation with residential and central areas of the territory. Thus, contributing to conditions of balance between urban development and the basic environmental system of the territory.

2. Methodology

The municipality of Chía is located in the northern conurbation of the city of Bogotá (**Figure 2**), with which it has intense functional and residential relations that induce a high and continuous connectivity and exchange of products and services [15]. Chía has experienced extensive population growth due to the social, economic and functional processes generated by the urban expansion of the city of Bogotá within the boundaries of the municipality [16]. The population growth rate in Chía during the period between 1993 and 2005 was 113.2% and decreased to 35.65% between 2005 and 2018, evidencing that the expansion was lower during this period. However, due to the high cost of the square metre in Bogotá, it is likely that the population growth rate will be constant over the coming years [17].

The municipality is made up of nine hamlets located around an urban centre in which the socio-economic strata 3, 4 and 5 are mainly found [18]. According to the Colombian socio-economic stratification system, strata 1 pertains to the lowest level and strata 6 to the highest level in terms of socio-economic development. In Colombia, the urban areas of the municipalities have grown the most. Chía in 2018 showed a growth of 79.8%, four points above the national percentage average of 75.5%. The remaining 20.2% is located

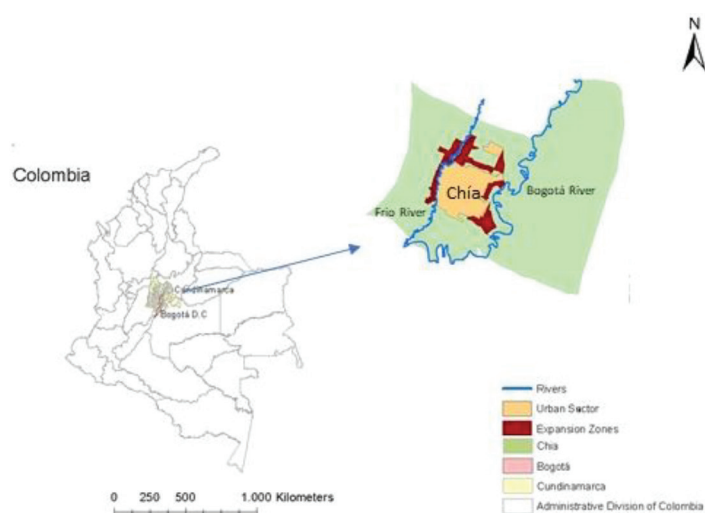


Figure 2.
Location of the municipality of Chía. Source: Authors.

especially in four of the nine hamlets of the municipality, Bojacá, la Balsa, Yerbabuena and Fonquetá, which evidences the de-ruralisation of several sectors [19].

The growth of urban land in Chía over the last 70 years is approximately 1000 ha, 55.8% of which belongs to the consolidated urban area. The urban land is distributed as follows: housing 69%, free land 18%, industrial land 5.62%, commercial land 1.27%, equipment 3.81% and crops 1.72% [20]. The municipality currently has two urban perimeters, the traditional one with an area of 590 ha, where the most important facilities are located, and a developing sector of approximately 40.5 ha [21].

This research seeks to identify the green corridors (GCs) found in the municipality of Chía, as well as to evaluate how to include them in territorial planning, especially regarding new expansion areas and in the definition of the municipal ecological structure in order to define areas of environmental quality at local and regional levels [22]. GCs are a fundamental tool in sustainable development policies as they are part of the environmental heritage of a territory and must therefore be integrated into planning and management processes [23].

The analysis of the GC of Chía considered the following zones and areas: the mountainous system of the eastern hills; the Bogotá and Frío rivers, which generate restrictions for economic and urban development activities, and which have a 30-metre zone for flood and flood management that is part of the public space of the municipality; and the mountainous system of the Majuy and Valvanera hills, which delimit the territory to the west. In addition, the environmental protection land was considered, which corresponds to the riverbeds of the tributary streams of the Frío and Bogotá rivers, with approximately 1300 ha of green areas in which effective public space sectors can be consolidated or environmentally sustainable road axes can be defined to complete the road system of the municipality that are defined in the territorial planning [24]. **Figure 3** shows that in the north–south direction, rivers are the main axes of articulation at the municipal and regional levels and have ecological and social functionality. Furthermore, from east to west, green spaces facilitate ecological connectivity along with a water system defined by the stream that lies on the perimeter of the municipality [25].

2.1 Regarding the urban expansion of the municipality of Chía

In Latin America, the definition of urban expansion areas is approached from a land use planning perspective. In Colombia in particular, such areas are defined in the Land Use Plan to ensure orderly and structured development [26] to incorporate land management instruments, organise activities and specify infrastructure and facilities needed at different times, and so Land Use Plans are the master plans according to which projects are implemented [27]. However, the review of different documents indicates that in Colombia, there is no specific policy that regulates urban sprawl. Generally speaking, urban policy promotes compact cities [28] through laws such as the Organic Law of Urban Development, which defines reserve areas for future extensions of the city, Law 61 of 1978, which in its Article 11, confers the character of public and social interest to the utility of these sectors and which is confirmed in Article 43 of Decree Law 1333 of 1986, which also establishes some limitations specifically regarding agricultural reserves, depending on the size of the municipality and its location with respect to the main urban centre [29]. In Colombia, the socio-economic stratification is a classification of residential properties that receive public services. It is carried out mainly to charge differentially by strata for residential public services, allowing subsidies to be allocated and contributions to be collected in this area. In this

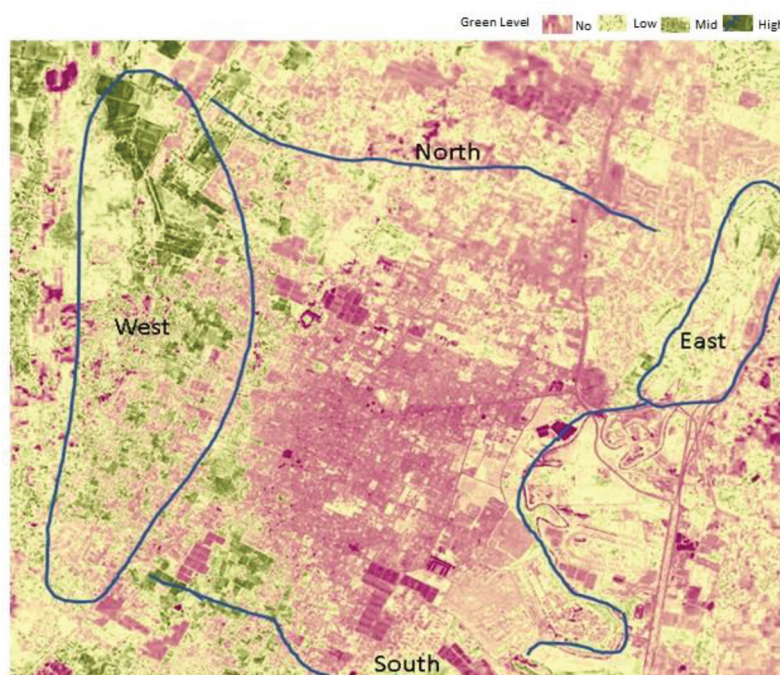


Figure 3.
 Identification of green corridors. Source: Authors.

way, those with more economic capacity are made to pay more for public services and contribute so that the lower strata are helped with bill payments [30].

Law 388 of 1997 known as the Law of Territorial Development establishes that the Plan de Ordenamiento Territorial POT (Land Use Plan) must be formulated in the different Colombian municipalities. In the year 2000, the municipality of Chía proposed the first document [2] in which the current urban expansion zones of approximately 299 ha were defined. In Chía, the first planning instruments date back to the 1970s, with Agreement 16 of 1974 and 32 of 1976. In 1990, the Plan was implemented, and in 1991, Agreement 011 was developed to discourage the construction and subdivision of rural areas. In 1994, the urban planning statute for the municipality of Chía was approved with Agreement 03.

Subsequently, in 2016, in Agreement 97, a revision and adjustment of the POT were proposed considering that it had not been renewed in 12 years as indicated by legislation. Nevertheless, it was suspended in 2019, so that currently the expansion zones defined in the POT dating from the year 2000 are still in force [31].

Currently, the predominant land use is residential, so that it becomes a necessity to generate a classification of uses in the expansion zones that balances commercial and industrial aspects to expand the economic capacity of the municipality and to thus contribute to regional capacity (Kurek et al., 2020). In this process, it is also necessary to evaluate the capacity of the current road network and to enhance its responsiveness to the mobility dynamics of the municipality. Therefore, the maintenance, renovation and projection of Chía's road network are fundamental elements required to advance the diverse territorial dynamics of the municipality.

With a view to obtaining precise information related to the presence of biomass and its density in the municipality area and its relationship with urban sprawl and

rural areas of Chía's territory, two main sources of information were chosen to be analysed and compared through a Geographical Information System (GIS).

The first information source is the 2018 multispectral satellite imagery information from the SAS Planet software that allows for the identification of images with red and infrared wavelength ranges, as well as visible wavelength ranges, and thus obtaining a Normalised Difference Vegetation Index (NDVI).

Using the image resources from multiple providers such as Google, Bing and ESRI, among others, the SAS Planet software facilitates downloading high-quality raster information to run multiple types of analysis over the ArcGIS platform for the purposes of identifying the greener areas of the territory of the municipality of Chía (Figure 4) with the Normalised Difference Vegetation Index (NDVI).

The ArcMap NDVI calculation method allows ranking the index from 0 to 100 values, identifying areas where biomass density is higher when values are closer to 100, and biomass density is low or non-existent where values are close to 0. This index rank can be obtained because '[t]he differential reflection in the red and infrared (IR) bands enables you to monitor density and intensity of green vegetation growth using the spectral reflectivity of solar radiation. Green leaves commonly show better reflection in the near-infrared wavelength range than in visible wavelength ranges. When leaves are water stressed, diseased, or dead, they become more yellow and reflect significantly less in the near-infrared range' [32].

Values from 0 to 20 are more likely to be clouds, snow, water, rocks or desert areas, as well as high-density urban areas without significantly green covered areas, where biomass tends to be critical. Values from 21 to 40 are commonly related to bushes, ground vegetation and non-dense biomass. Such values are most likely to be found in urban areas where vegetation is presented as a dispersed pattern.

Values from 41 to 60 represent very positive biomass presence. Such values are most likely to be dispersed forests, medium dense woods, where vegetation tends to be somewhat greener, such as parks, forest reservoirs, mountains. Values from 61 to 80 are related to tropical and rain forest, high-density biomass where leaves are highly green and hydrated. Values equal to or higher than 81 may appear where very high density is located but are rarely obtained from NDVI analyses made from urban areas satellite images.

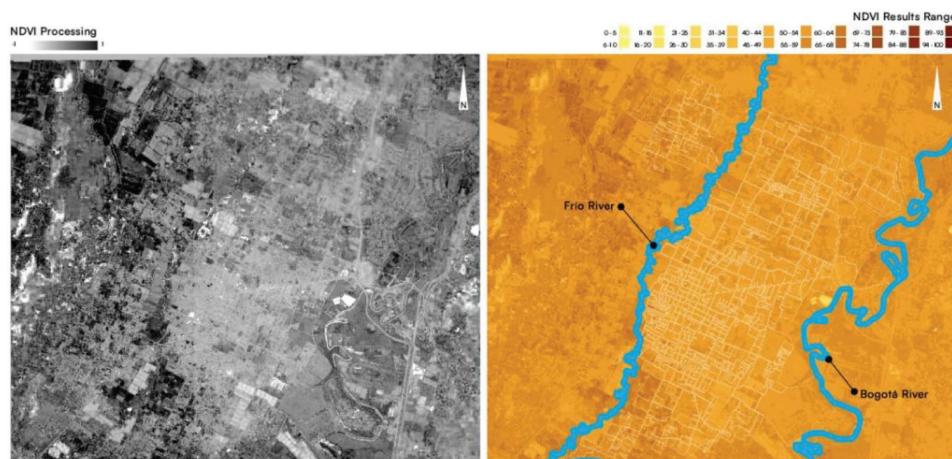


Figure 4.
NDVI analysis. Source: Authors.

The second information source selected is the 2018 version of the Colombian National Population and Housing Census, which identifies urban densities and other additional demographic information related to housing, population and life quality on an urban block scale basis.

Demographic densities were used in this case to look for possible relations between biomass density and urban areas of the municipality of Chía, where urban blocks accumulate different average NDVI values according to the presence of greener areas among them, which can be compared with the number of inhabitants per hectare residing in each urban block.

As a contribution to the study of urban green infrastructure, space syntax is applied to understand the urban morphology [33] and how the city spaces are connected to each other through the urban accessibility roads or axes. As space syntax is characterised by the study of the social and logical behaviour of space in terms of mobility, its application is considered appropriate. The aim is to deepen the knowledge of the organisation of the city in its urban axes in the context of a peripheral city and what spatial relationships may exist when compared with the green spaces of the city, that is, the urban green infrastructure.

To this end, two syntactic measures are applied given their potentiality for spatial analysis, namely connectivity and choice. Connectivity is related to the intersection of urban roads and therefore indicates areas or zones of the city where there is greater conglomeration in urban accessibility. Choice indicates the probability of a greater flow or choice of certain urban roads. To obtain these syntactic measures, a map of urban axes is drawn up to subsequently obtain the axial map of the area under study.

3. Results and discussion

The processed NDVI values show that the municipality of Chía presents biomass density common values from 35 to 70, with 50 being the most common value found, which implies that this territory has a very positive biomass presence on the analysed

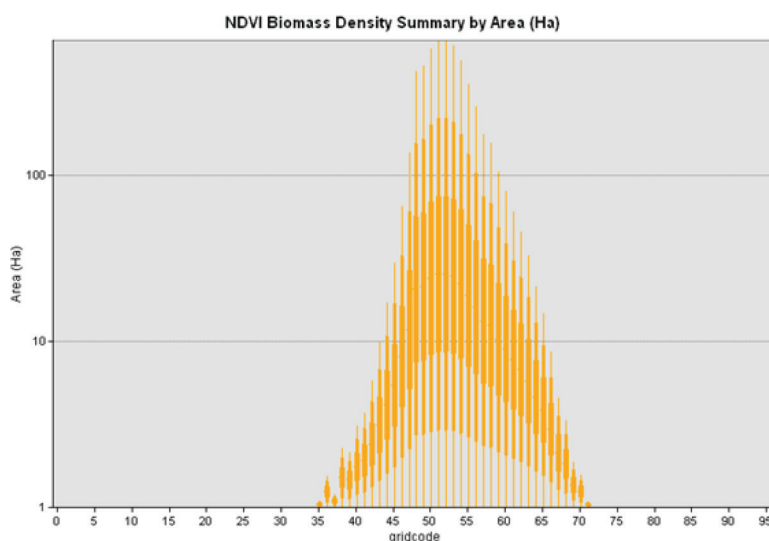


Figure 5.
NDVI analysis results. Source: Authors.

surface, with hundreds of hectares that contain different biomass elements such as trees, grass, dispersed forests and medium dense woods (**Figure 5**).

Heavily dense forests and highly dense biomass are concentrated only on the western side of the municipality, mainly on the western bank of the river Frío, where high-density biomass shows important spots that should be preserved, mainly in those zones close to main urban area.

The municipality of Chía has been growing towards the north and the south, being limited by the presence of the rivers Bogotá and Frío. This area in between the rivers displays a significant lack of biomass density compared with the western side of the municipality, where rural areas are somehow preserved with the only exception being a northwest area where the urban spot has grown at the western side of the river Frío, where it is possible to find a zone where high-density biomass can still be located among parts of the urban area.

The centralised downtown area of this municipality shows medium urban density patterns with values between 245 and 669 inhabitants per hectare, where NDVI values for the urban blocks contained in this area register values ranging from 12 to 43, indicating that there is no significant presence of biomass (**Figure 6**).

By comparing the grid code result from the NDVI analysis averaged for each urban block, and the values for urban density, it is possible to visualise that the larger portion of inhabitants reside in areas where NDVI values range from 42 to 52, mainly in the suburban areas of this municipality where the urban sprawl model has been intensively used (**Figure 7**).

The expansion areas of this municipality are located at the western, northern and eastern bounds of the main urban area and almost completely contained by the above-mentioned rivers, so that these planned expansion areas extend at least towards the northern and eastern bounds. The expansion areas lack highly dense biomass elements or significant woods or forests, and they continue the patterns that are visible in the main urban areas where there is no evidence of any strong biomass connection between the Frío and Bogotá rivers.

On the contrary, the westbound planned expansion areas indeed display a significant presence of biomass inside the marked polygons, which is a consequence of

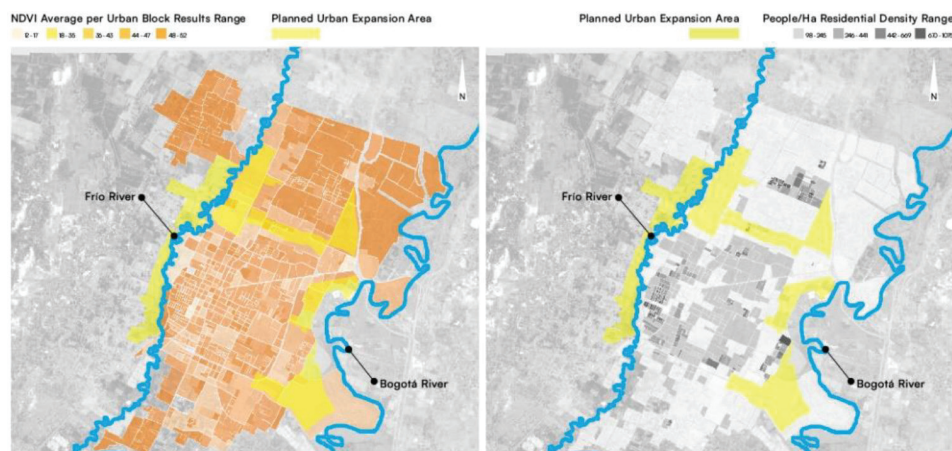


Figure 6.
NDVI and urban density for the urban area of the municipality of Chía. Source: Authors.

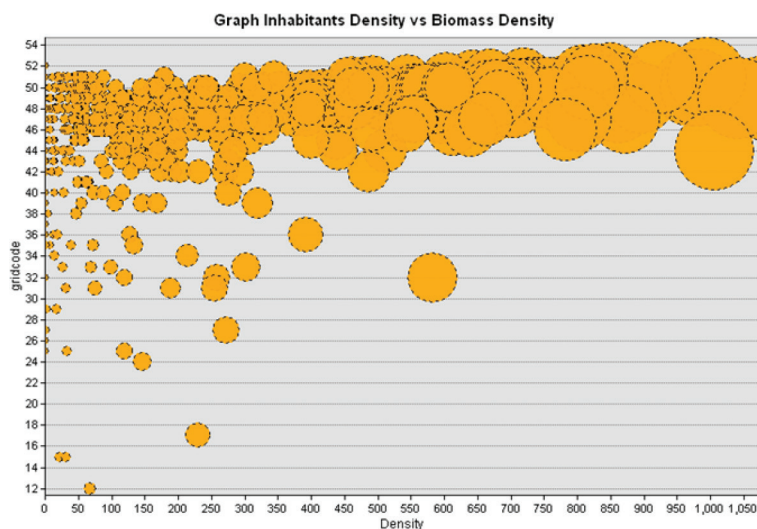


Figure 7.
Urban density vs. biomass density. Source: Authors.

the existence of some preserved rural areas where high-density biomass elements are present, which is a situation that allows us to conclude that those elements are in imminent risk of disappearance when expanded urban areas get built on the west banks of the river Frío (**Figure 8**).

By applying space syntax, we obtain the axial maps of the urban area of Chía with the connectivity and choice measures, including the respective expansion areas defined by the POT to facilitate the understanding of the results obtained (**Figure 9**). Regarding connectivity, the road with the highest values is located diagonally in the urban area and therefore away from the urban green area. Two other urban roads with high values are also located longitudinally, with the first one on the south side not coinciding with any consolidated green area, and the second one being located close to the northern expansion area. The zone near the expansion area to the east results

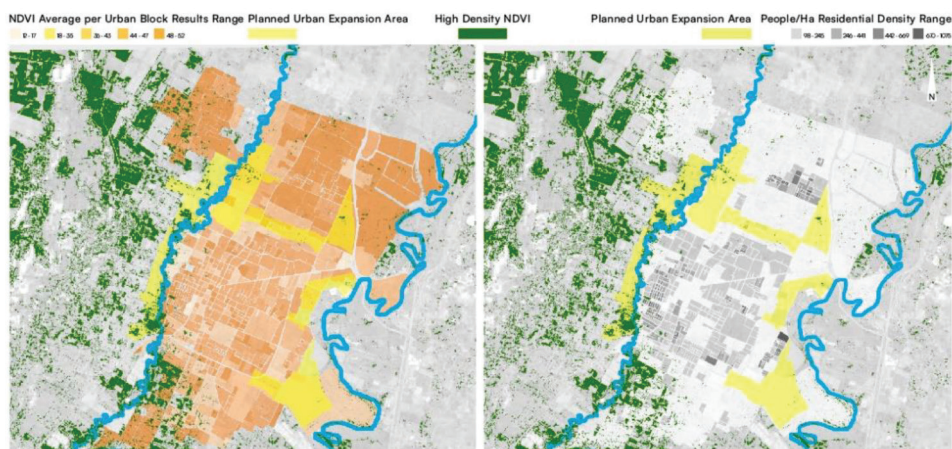


Figure 8.
High-density biomass, NDVI and urban density for the urban area of the municipality of Chía. Source: Authors.

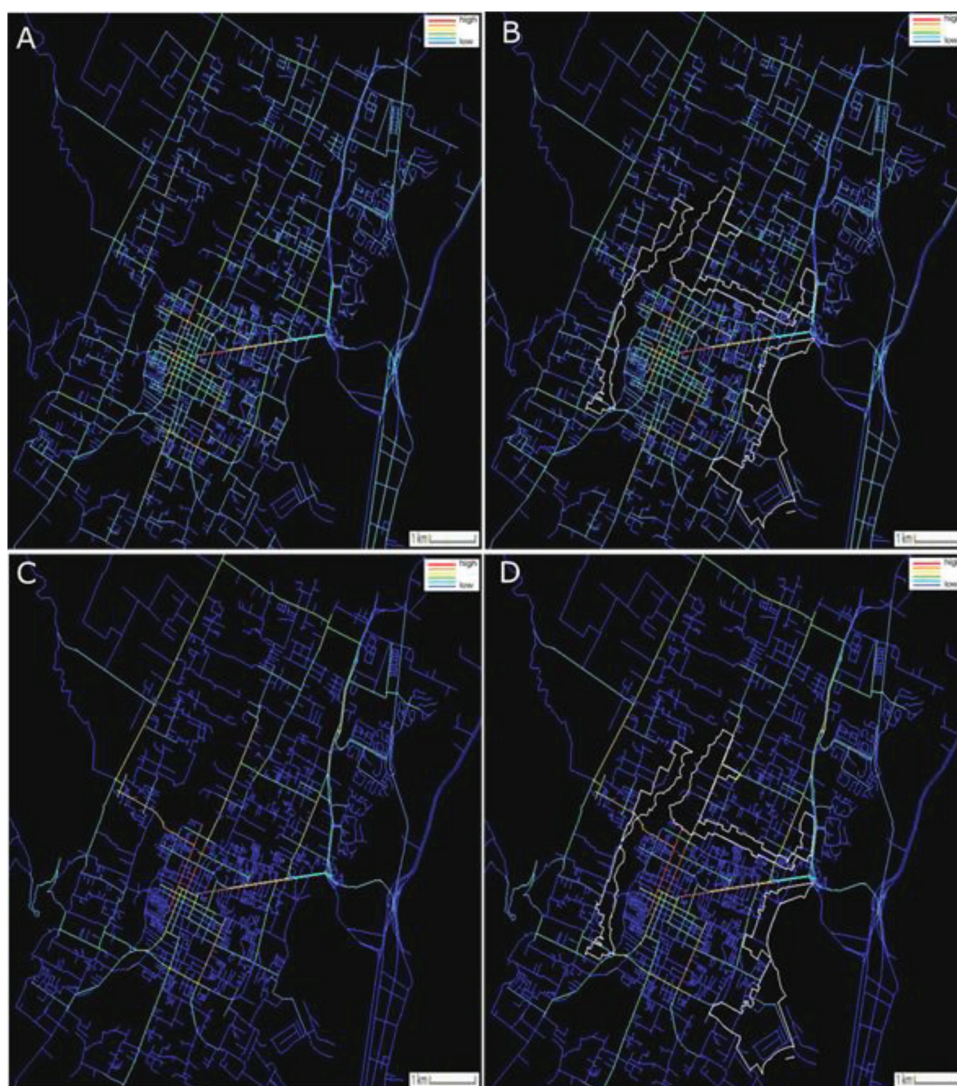


Figure 9.

Axial maps of Chia's urban space with the spatial variables: Connectivity (A), connectivity with expansion area (B), choice (C), choice with expansion area (D). Source: Authors.

from urban roads with low connectivity values. This zone with the highest concentration of green area, when analysed from the perspective of urban accessibility, results in a zone of low urban connectivity, that is, an area not inserted in the consolidated urban space, but rather in the peripheral space of the city.

On choice, the results show that two roads obtain higher values, which are defined by two longitudinal axes located near the expansion area to the North, where the green density is higher. One of these roads crosses the expansion area. However, there are no other roads that have a high probability of being elected in the urban accessibility that coincide with the consolidated green area.

In terms of environmental benefits, social well-being and economic development of communities, the importance of green infrastructure is unquestionable.

Nevertheless, the relationship between urban growth and green infrastructure location is a key factor contributing to urban vitality and sustainable urban growth. In metropolitan regions, areas remaining between the central city and other historic or emerging cities are decisive for an appropriate balance between green and built infrastructure. This can be explained, firstly, by green infrastructure contributing to a balance in urban development by mitigating negative externalities produced by urbanisation, such as pollution; secondly, by green infrastructure being fundamental for the protection of aquifers or natural areas that are highly vulnerable; and thirdly, by the fact that green infrastructure can consist of areas for urban agriculture, contributing to the population's food security.

In this study, the proximity level between green infrastructure density and population density is assumed as a key indicator of an adequate balance between urban growth and green infrastructure. This relationship may be determining the greater or lesser degree of population accessibility to these types of infrastructure.

In the case study of the Bogotá-Sabana Northern region, and more specifically in the case of the metropolitan city of Chía, the intense sprawl and emerging polarised growth do not seem to be contributing to the generation of a solid green infrastructure system as is evidenced by the relationship between low population density and low density of green infrastructure. However, the urban expansion public policies do not seem to be clearly aimed at preserving the conditions of natural green infrastructure, especially around the Frío River, which flows alongside the municipality at the western boundary of the city's historic urban centre. In general terms, the largest urban expansion areas are found along the banks of the Frío river. These expansion areas are planned with a medium-density urban form, following the compactness of the historical city. Although there are still no precise definitions of planned green and built types of infrastructure in urban expansion areas, principles of green infrastructure connectivity and functionality as a system do not seem to be guaranteed, which should be a priority of public policies for planning urban growth.

Urban growth policies in metropolitan territories must also be approached from a multi-scale perspective given the reciprocal impacts between natural and built types of infrastructure. Therefore, a solid green infrastructure should be a planning strategy that enhances the resilience of cities and provides ecosystem services to their communities.

Urban vitality and functionality promote and guarantee urban quality from the citizenship perspective. In urban development, green infrastructure takes on a relevant role and considering the results obtained by space syntax, urban morphology indicates possibilities of correction in urban design and planning. As an urban planning strategy, a concentration of green area in the expansion zone to the east near the Frío river can be envisaged. However, it seems incomprehensible that this area is not defined by nearby roads with average connectivity values to facilitate the approach and spatial integration in the city.

4. Conclusions

The growth of the municipalities of the so-called metropolitan region of Bogotá has been informal and peripheral, especially given the fact that the different characteristics that define such municipalities are not adequately and coherently articulated, which has affected the ecological structure, that is, the network of spaces and corridors in which the ecological and biodiversity processes that constitute the green space of the municipalities are developed. Accelerated urban growth has generated a great

territorial imbalance associated with the challenges of environmental sustainability and climate change, which are essential elements of urban planning.

Given its location, the economic and mobility dynamics due to the increase in new homes are constant. Thus, the housing typologies that are developed are a function of the economic capacity of the new residents. Therefore, in the urban centre, the socio-economic strata 3 and 4 predominate with houses having fewer square metres and being built in height, while in the villages the population belongs to strata 5 and 6, and houses are built under a dispersed housing typology that responds to a low-density planning model.

Currently, in the municipality, there is a disconnection and disarticulation between public spaces and green areas, with the main uses, activities and facilities, as well as a road infrastructure having no connectivity and little accessibility (pedestrian, bicycle and vehicular) with the new urban developments. Considering the provisions of the POT and the fact that the urban growth of the capital city points to the north, it is likely that this dynamic will not only be maintained, but will be accelerated, since Chía has already defined expansion areas that should be developed in the future.

The urban area had growth among the two main rivers in the area, blocking any kind of ecological connectivity among them. Furthermore, there is no evidence of biomass corridors that connect the space between the rivers, and the green areas identified through the NDVI analysis result more commonly to be none build areas or low-density edifications and rarely parks or natural corridors where biomass is meant to be preserved.

The fact that the main zone with the highest density of urban green area does not include any roads with medium connectivity value in the urban morphology allows us to conclude a weak urban integration. Moreover, we can observe the decrease of urban functionality and therefore the consolidation of green infrastructure understood as a spatial element of urban development and benefit for the quality of life in the city. Urban vitality and functionality promote and guarantee urban quality from the citizenship perspective. In urban development, green infrastructure assumes a relevant role, and taking into account the results obtained by space syntax, urban morphology indicates possibilities of correction in urban design and planning.

As an urban planning strategy, a concentration of green area in the expansion zone to the east near the Frío river can be observed. However, it seems incomprehensible that this area is not defined by nearby roads with average connectivity value to facilitate the approach and spatial integration in the city.

5. Study limitations and future research lines

The most significant limitation of the study is the existence of open data and the fact that these data are not up to date; moreover, the scarcity of information in the land use plan is due to its lack of updating in relation to what is established by the municipal regulation. This may condition the development of the research process. The built structure registration data also condition the study and the understanding of this data with the urban green infrastructure, besides the scarce information that exists in the land use plan. Possible research future lines can be considered the study of urban suburbs or urban sprawl boundaries, given their built-up pressures. The connectivity analysis of the urban green infrastructure in the metropolitan region of Bogotá is also important due to the new territorial planning instrument at regional

scale; therefore, its incorporation in the urban planning exercise of the municipalities surrounding the metropolis is relevant. Finally, we highlight the need to insert the urban green dimension of the municipalities in public policies, which makes up a line of research with potential in relation to climate change.

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Conflict of interest

“The authors declare no conflict of interest.”

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